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Tank Wars II User Manual

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Tank Wars II: The Sustained Combat Model is a computer simulation of sequential engagements between mechanized combatants. DOD agencies and their contractors use it to evaluate the combat effectiveness of tanks and other fighting vehicles as well as subsystem improvements.

This report explains how to use the model. It gives a brief overview of the model. Then it tells where to get input and how to prepare it. Next, it discusses the output. Finally, it tells how to obtain, install, and perform test runs.

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1. INTRODUCTION

Tank Wars II: The Sustained Combat Model is a computer simulation of sequential engagements between mechanized combatants; one side of which is not resupplied. It is routinely used at various military installations and by private corporations for evaluating the combat effectiveness of tanks and other fighting vehicles. The systems being evaluated (usually U.S. systems) defend against one or more waves of attackers without resupply, or on the attack, engage one or more defended positions without being resupplied.

Each engagement is simulated in detail. The critical events in such an engagement include search, detection, selection, acquisition, firing, impact, damage, target disengagement, and reengagement. Interwoven with these events are motion events and intervisibility events. If desired, the program will print an event history for detailed study.

The model includes three types of engagements, two generic armaments, three categories of functional losses, and two types of false targets. Table 1 contains an extensive list of model features. The three scenarios are attack, defense, and a meeting engagement. Guns fire kinetic energy (KE), or high-explosive antitank (HEAT) rounds while missiles may be guided-to-impact or fire-and-forget systems. Systems may fire while moving or halt to fire and, in either case, may suffer loss of mobility, firepower, or both and may be catastrophically killed. In addition to the weapons systems being evaluated, there may be a number of active or passive decoys and there are generally some false targets in the scenario.

To give a flavor for the capabilities of the model, the following list of questions has been addressed in studies using the model:

(1) Is new tank concept X, with more armor and better projectiles, significantly more effective in combat than the M1 tank?
(2) Is new system Y, with an automatic loader but lighter armor, more effective than the M1 tank?
(3) Can STAFF missiles fired from helicopters be effective against tanks?
(4) Should tanks spread their fire over all foe or concentrate their fire?

Table 1. Model Features

Armament/accuracy round reliability KE, HEAT, missiles (incl. STAFF) time of flight probability of sensing miss S-S accuracy depends on prev. rounds Driver routines loop through scenarios opening ranges force ratios multiple replications waves of threat systems regrouping Fire cycle characteristics modeled ammo consumption burst fire first round time subsequent round times manual loading, load assist, automatic loading Intermediate output event histories logic tracing event tracing as scheduled, canceled, and retrieved calendar dumps Measures of effectiveness ammo consumption blue tanks killed red tanks killed blue win probabilities red win probabilities exchange ratios	Miscellaneous characteristics multiple kill levels pinpoint and nonfiring detection various target disengagement policies model widely used 21 levels of target priority simple terrain Program design event sequenced time stepping for detection stochastic FORTRAN 77 modular structured indented code 3,900 lines of code Scenario characteristics modeled multiple waves of Red threat systems multiple combatants false targets passive and active decoys Vehicle characteristics modeled disjointed turret and hull cardioid or other aspects moving targets fire on the move halt to fire gross motion full defilade, hull defilade, fully exposed

(5) Should the size of the gun on the M1 tank be increased in light of the smaller number of larger rounds it will be able to carry?

(6) Do particle beam weapons on ground combat vehicles have merit?

(7) Is it worthwhile to increase the accuracy of tank projectiles?

(8) Should the tank gunner disengage the target after simply hitting it or should he fire until it is catastrophically killed?

(9) Is new projectile Z significantly more effective than the fielded one?

2. MODEL DESCRIPTION

The model is written in FORTRAN 77 for portability and is based on the old TANK WARS model which is still running at over a dozen installations. It was written using top-down structured programming techniques including indenting to show the structure of the code and consists of approximately 3,900 lines of code broken into short, logical modules.

The model treats any armored vehicle, but for brevity, this report calls them all "tanks." It is also adaptable for other fighting entities, although this adaptation may be difficult for fast moving entities such as aircraft in a dogfight.

The model simulates combat between tanks grouped into two forces called Blue and Red. It currently handles a total of 20 tanks; however, this can be increased by changing two parameter statements and recompiling the program. The model plays such tank characteristics as burst fire, target disengagement policies, and four levels of kill.

The following goals were in mind when the model was constructed: correctness, modifiability, ease of input preparation, and understandability of output. Modifiability and understandability were achieved by creating a stochastic model which simulates each significant event in each engagement. The randomly generated events are printed in an event history, if desired, so they can be studied in detail.

To put this in perspective, there are basically two ways of simulating combat. You may 1) move through the engagement while keeping track of the distribution of all possible intermediate outcomes or 2) move through the engagement each time selecting a single outcome and repeat this for enough engagements to produce a statistically significant picture of the distribution of final outcomes. The first method involves the complex convolution of many distribution functions and is impossible for the layman to trace, if indeed it is possible for the model builder to construct. It is also difficult to modify and extend. The second method is easy to comprehend because simple event histories can be examined. It is also fairly easy to extend or modify such models.

2.1 Features Simulated.

2.1.1 Waves of Threat Systems. The program simulates a unit of Blue systems defending against one or more waves of Red attackers, a unit of Blue systems attacking one or more positions of Red defenders, or a unit of Blue systems encountering one or more Red units in a series of meeting engagements. In each of these cases, the Blue systems are not resupplied. The purpose of modeling waves of Red tanks without Blue resupply is so that ammunition load may be evaluated under sustained combat conditions. Normally, gun systems carry 30 or more rounds and tend to win or lose before they run out of ammunition; however, missile systems carry fewer rounds and may tend to run out of ammunition before the engagement is over. The sustained combat feature is essential for properly evaluating such limited load systems.

To illustrate how the model actually simulates sustained combat, consider the following case. Three Blue tanks meet three Red defenders. If the Blue tanks win the engagement, they meet (with reduced ammunition) another trio of Red tanks and so on until they can no longer fight. Assume also that initially, there are 1,000 such Blue units—that is, "1,000" replications are desired. What the model actually does is simulate the 1,000 first engagements and record the remaining ammunition available for those Blue tanks that are still able to shoot and move at the end of these first engagements. If the sides are equal, about half of the Blue tanks would survive each of the 1,000 first engagements, so about 1,500 are available to fight a second engagement. These are regrouped into say 500 units of three and 500 second engagements are simulated. If one or two tanks are left over so that a group of three cannot be completed to fight in the second round, this is recorded and the odd tanks are fought in later engagements. This process is repeated until no Blue systems are left to fight or until a predetermined number of Red "waves" have been engaged.

In hindsight, it can be seen that, if ammunition is not a limiting factor and evenly matched combatants fight to the death, half or more of the Blue tanks are destroyed in each engagement and the expected number of engagements a given tank will fight in is two or less. In simulations run to date (with evenly matched forces and say 30 rounds on board), tanks usually die long before they run out of ammunition. Ammunition tends to become critical if the vehicle can only carry a small number of rounds (e.g., 6–12 missiles). It also may be critical if the forces are mismatched or did not fight to the death.

2.1.2 Initial Deployment. At the beginning of an engagement, the tanks of the attacking force (Blue) are centered about the origin on the y-axis facing East. The Red systems are also centered on the x-axis East of the Blue systems and facing West. The distance between Blue and Red is the opening range. If the opening range is 3 km, these lines are 3 km apart. The tanks on each line are spaced 100 m apart.

2.1.3 Types of Systems Simulated. The model simulates guns and missiles, fire-on-the-move and halt-to-fire systems. For guns, it simulates single rounds or "bursts." For gun systems, KE and HEAT rounds are treated somewhat differently and they may either halt-to-fire or fire-on-the-move. All the missile systems are treated as halt-to-fire systems and remain halted until missile impact. Simple missile systems launch a single missile and guide it until impact. Simultaneous missile systems guide up to five missiles to five separate targets simultaneously. Rounds are aborted if missile systems are firepower killed but not if gun systems are firepower killed. The program can simulate fire-and-forget missiles by treating them as ballistic projectiles.

2.1.4 Decoys. If desired, some of the targets on a side may be decoys—some may be passive, some may be active. The model simulates this by never letting the passive decoys fire and by letting the active decoys "fire" but not scheduling an impact for these "rounds." The passive decoys draw fire if they are detected in accordance with the usual nonfiring detection algorithm. The active decoys may be detected when nonfiring or their simulated muzzle flash may be detected. The probabilities of detecting, hitting, and killing these decoys are the same as for real targets in the model, and though this is probably not correct, no data are available to model it better.

2.1.5 False Targets. Tank commanders and gunners may mistake vegetation and other objects as legitimate targets. The model plays this by treating a fraction of the new "targets" as false targets. The appropriate fractions are unknown, but 0.7 has been used for hull defilade targets and 0.3 for fully exposed targets. The user is free to input his own values. After selecting a false target, the tank fires on it and at impact, recognizes it is a false target and reselects.

2.1.6 Kill Criteria. The levels of kill are M for mobility kill, F for firepower kill, M&F for mobility and firepower kill, K for catastrophic kill, and I for inactivity kill. In the case of an M-kill, a moving target immediately begins to slow down and cannot move after it halts. In the case of an F-kill, the target is not allowed to fire any more rounds during the engagement. Guide-to-impact missiles in flight are aborted, but fire-and-forget rounds which were fired before the F-kill continue on their flight. It is these rounds in flight which cause "simultaneous" kills resulting in an all-dead outcome. They are not as unlikely as might be expected. When both an M- and an F-kill are accumulated, the target becomes inactive and this should be recognizable after a period of time. In the model, when an M&F-kill has been achieved on a target, the kill type is "bumped up" to an I-kill after a user-specified period of time. A K-kill is defined to be damage to a vehicle which is so severe it is not economical to repair. When this occurs, the target can no longer move or shoot and everybody knows it. When a tank is I-killed or K-killed, every tank engaging it disengages from it and attempts to select a new target. The dead tank is ignored thereafter.

2.1.7 Target Disengagement. The model plays various target switching policies. According to U.S. doctrine, a U.S. tank continues to fire at a tank target until the target exhibits a large flash or volumes of smoke, indicating that the ammunition or fuel has been hit. This is roughly equivalent to a K-kill in vulnerability analysts' parlance. The FRG doctrine says shoot until a hit occurs, and the USSR doctrine is assumed to be the same as the U.S. doctrine. In any case, the model gives the user a broader set of options. These options are as follows:

(1) Permanently disengage from I-killed and K-killed targets.
(2) Permanently disengage as in option 1 or temporarily disengage after hitting the target.
(3) Permanently disengage as in option 1 or temporarily disengage after shooting a user chosen number of rounds.

Under each of these options, burst firing weapons delay disengagement until the end of the burst. Under option 3, missile systems disengage at impact or when the target is K-killed.

If a new target is "on deck," the firer switches to it using the logic described later for target selection. Otherwise, the program schedules the reengagement of the oldest partially serviced target and continues to search for new targets.

2.1.8 Win Criteria. Currently, a side wins an engagement when the other side cannot shoot back. This occurs if all systems on the other side are firepower killed (or worse) or run out of ammunition.

2.1.9 Motion. The program moves each attacking vehicle along a preplanned path. The paths are identical in shape but are offset from each other and are either straight line paths or sinusoidal paths. Attacking tanks move north along these paths from the initial deployment. The sinusoidal path is included to simulate the normal motion of tanks as they avoid obstacles and to generate the resulting target induced aiming errors. The user specifies a maximum acceleration which defines the amplitude of this lateral motion. The paths of individual attackers are spaced 100 m apart on the east-west axis. The tanks move on their paths *independently*, slowing up, halting, accelerating, and cruising as circumstances dictate. These four motion events are discussed in detail later.

2.2 Events Simulated. This section gives a general idea of how the program simulates a single engagement.

2.2.1 Initiation of an Engagement. First, all the tanks on the Blue side are given a prescribed number of rounds. They are placed in hull defilade if defending and if stationary, are randomly oriented according to the cardioid or other user-chosen distribution. Second, search is initiated at time zero.

2.2.2 Search. The Search event occurs each second until all tanks that can search find all targets of interest, after which Search ceases rescheduling itself. During the engagement, if a target vanishes and reappears, the Appear event reinitiates Search. Each time the Search event occurs, the model examines each Red-Blue pair of tanks to determine whether the target contrasts with its background sufficiently to be seen and whether the firer actually will see the target in the next second. If so, a detection is scheduled for that firer on that target at a random time in the one second interval. The Search event is unique in that it deals with all firers and all targets, whereas the other events usually deal with a single tank or a single firer-target pair.

2.2.3 Detection. Nonfiring detection is scheduled by the Search routine. In addition to nonfiring detection, a target may be detected because of its signature during firing. The program treats this as follows: Any time a tank fires, the program checks all enemy tanks. If the enemy tank is searching for a target, the program draws a random number to see if the searcher detects the tank that is firing and, if detected, schedules an immediate detection and cancels any detection of the target by the firer which is later on the list of scheduled events.

Whichever method of detection occurs, the Detect event simulates a detection and schedules a Select event for the firer if he is able to handle a new target.

2.2.4 Selection. When a tank is ready to engage a target, it selects from among the targets it has detected with the following priorities in mind. A target that has fired in the last 30 s has priority over one that has not. One that is closer has priority over one that is farther away, because the closer one is easier to hit and is more dangerous. One that is stationary or slowing up has priority over one that is not because it is easier to hit and it may be halting to fire. One that is within recognition range (say 1.5 km) and has a target of its own may be pointing in the general direction of the firer, and the firer may be able to recognize this, so such a target is also given a higher priority.

Table 2 shows the two ways the model handles these rules. Scheme 1 selects old hit targets over new targets and should be used when the probability of a firepower-only kill is low. Scheme 2 selects new targets over old hit targets and should be used when the probability of a firepower-only kill is high.

2.2.5 Slow Up. If a system is a halt-to-fire system or if it is M-killed, it begins to slow up. This event simply schedules a Halt event at the appropriate time.

2.2.6 Halt. If the system is a halt-to-fire system, the Halt event schedules a Fire event.

2.2.7 Firing. First, the firing routine updates the orientation of the firer's turret, finds the range to the target, schedules an Impact event, and updates the number of rounds on board. Then the firer acts on the following general rules:

(1) If a halt-to-fire system is in the midst of a burst, complete the burst before moving.
(2) If cannot shoot, move.
(3) If cannot move, shoot.
(4) If the system guides single missiles to impact, wait until impact before firing another missile.
(5) If the system can guide multiple missiles to impact and fewer than the maximum are being guided, attempt to select another target.

Table 2. Target Priorities

Scheme 1	Scheme 2	Status of Target		
1	1	Close	missed	old tgt that fired in last 30 s
2	2	Close	missed	old tgt that has tgt
3	3	Close	missed	old tgt that is stopped or slowing
4	4	Far	missed	old tgt that fired in last 30 s
5	5	Close	missed	old tgt all others
6	6	Far	missed	old tgt that is stationary
7	7	Far	missed	old tgt all others
8	8	Close	—	new tgt that fired in last 30 s
9	9	Far	—	new tgt that fired in last 30 s
10	15	Close	hit	old tgt that fired in last 30 s
11	16	Close	hit	old tgt that has tgt
12	17	Close	hit	old tgt that is stopped or slowing
13	18	Far	hit	old tgt that fired in last 30 s
14	19	Close	hit	old tgt all others
15	20	Far	hit	old tgt that is stationary
16	21	Far	hit	old tgt all others
17	10	Close	—	new tgt that has a tgt
18	11	Close	—	new tgt that is stopped or slowing
19	12	Close	—	new tgt all others
20	13	Far	—	new tgt that is stationary
21	14	Far	—	new tgt all others

(6) If target disengagement criteria are met (switch after N shots or target was K-killed in midburst and burst now complete) disengage from the target.

(7) If halted, move before shooting another round.

The program also treats the possibility of foes detecting the firer's firing signature at firing time. To do this, it draws a random number for each foe that can detect the firer and compares it with the pinpoint detection probability. If the random number is less than the pinpoint detection probability, the program schedules a detection of the firer by the foe immediately.

Finally, the Fire event treats flashing decoys by allowing pinpoint detections but failing to schedule an Impact event.

2.2.8 Impact. The impact routine simulates the activities surrounding the impact of a round in the vicinity of the target and schedules the consequences of that impact. If the target has gone into full defilade, nothing happens. If the target is a false target, this fact is recognized at the time of impact and a new target is selected. Otherwise, the impact in the vicinity of a real target is treated.

First, the model determines what the round does. If the target is a real target, the routine determines whether the shot was a hit or a miss. If it was a miss, the program determines whether the miss was sensed or not and notes this so that the accuracy can be adjusted for succeeding rounds. If the round was a hit, this is noted so the accuracy can also be modified for succeeding rounds. At this time, the model randomly draws a target orientation from the cardioid or other angular distribution and draws the errors associated with the round to find out whether the round hit the turret or hull or missed entirely.

Second, the model determines what the firer does. If the round is a guide-to-impact missile, the firer attempts to select a new target. If no new target is available and he is an attacker, he begins to move again. If the round is a bullet or a fire-and-forget missile, the firer may switch targets depending on his target disengagement policy. And finally, missile systems that have just emptied a pod pop down to reload if they are in a defensive posture and are not guiding a missile to impact.

2.2.9 Damage. The Damage event treats the consequences of a hit on the target and, in the case of a catastrophic kill, disengages those who are engaging the target. Dud rounds are discarded. The routine then determines whether there was a kill or not and, if so, what type of kill. If this is the first mobility kill on the tank, the program cancels all mobility events for the target and schedules a halt if necessary. If this is the first F-kill on the tank, the program cancels pending fires, selects, reloads, and aborts any guide-to-impact missiles the target may have in the air. If the target is still mobile, the program may schedule Accel and Hide events. If the target has just lost both mobility and firepower, the appropriate scheduled events are canceled and an I-kill may be scheduled for the near future; this simulates tankers discarding a tank that remains inactive for a period of time. If the target has just been catastrophically killed, all events for the target are canceled. All tanks engaging the killed target disengage, and each is scheduled to select a new target.

2.2.10 Accel. The Accel or Acceleration event occurs when targets are no longer available for servicing. This may be because a target has vanished, been K-killed, the firer has been F-killed, or under certain other conditions. The Accel event simply schedules the Maxvel event at the appropriate time.

2.2.11 Maxvel. Upon reaching cruise speed, the Maxvel event occurs. It has not been mentioned before, but Maxvel, as well as the other three motion events, must perform some bookkeeping so that the position and velocity of each tank can be recovered when necessary. Other than this, the Maxvel event does nothing.

2.2.12 Reload. If the system is a missile system with several pods of missiles and the last missile in a pod was fired, the Fire event schedules a Reload event for the time when the reloading is to be completed. Then, when the Reload event occurs, it schedules a new Select event so that a new target may be engaged.

2.2.13 Vanish. At the start of the engagement, the program assumes that all systems have just come into line of sight of their foes. At this time, and whenever line of sight begins, a Vanish event is tentatively scheduled. If moving tanks slow up and/or halt before vanishing, the program then reschedules the Vanish event because of the delay involved.

The length of the line-of-sight segment is simulated by a random draw from a Wiebull distribution which has been fitted to terrain data. The time to reach the end of this segment is then calculated from the length of the segment and the cruise velocity.

Upon vanishing, an Appear event is scheduled; all missiles launched toward or from the now concealed tank are aborted; lines of sight are unset; and the appropriate Select, Detect, and Fire events are canceled. Systems firing at the now concealed tank are rescheduled to select a new target. Ballistic projectiles like KE and HEAT rounds enroute toward the concealed tank continue in flight but will hit intervening terrain at impact time. Top attack projectiles like STAFF are unaffected by a Vanish event.

2.2.14 Appear. Upon vanishing, the length of the out-of-sight segment is drawn from a second Wiebull distribution and the program schedules an Appear event. When the Appear event occurs, it tentatively schedules the subsequent Vanish event. It also restarts the search sequence if necessary.

2.2.15 Hide. The Hide event is somewhat similar to the Vanish event in that line of sight is broken, missiles are aborted, and ballistic projectiles flying toward the hiding tank are ignored when impact occurs. The tank goes to hide because it has been F-killed, a Slow Up event is scheduled and, when the subsequent Halt event occurs, the tank ceases to participate in the engagement.

2.2.16 Finish. The Finish event occurs at a user-specified time or when there are no other events remaining. Its purpose is twofold: to break out of an infinite loop of events and, in any case, to collect statistics at the end of an engagement.

2.3 Organization of the Model. The routines in the program fall into four categories: 1) a set of driver routines for looping through various types of engagements; 2) a set of model routines for simulating each individual engagement; 3) a set of simulation support routines which control the timing of events and store information about temporary entities; and 4) a set of utility routines.

The driver routines are a recent improvement in the model, which takes over much of the drudgery of building files to drive the model and concurrently avoids much of the human error in preparing input for the model. These routines read input and then loop through the desired scenarios which are either meeting engagements, Red attacks, or Blue attacks. Inside the routine which deploys the tanks at various opening ranges is another routine which loops through waves of attackers and another inner routine which loops through the desired number of replications of individual engagements. In pseudo code, this looks as follows:

```
Read game control information
FOR Blue and Red
    Read miscellaneous data
    Read accuracy data
    Read vulnerability data
ENDFOR
FOR each case
    read scenario, #Blue, #Red
    FOR each desired opening range
        FOR desired number of replications
            Simulate an engagement
        ENDFOR
    ENDFOR
ENDFOR
```

2.4 Conventions.

2.4.1 Units. Internally, the program uses standard metric units but expects inputs and generates outputs in more recognizable units as necessary. Accuracy data is available in mils where 1 mrad = 1.0186 mils, but the difference is so small that they are assumed to be equal. Table 3 lists the units used.

Table 3. Units

Type	In I/O	Internally
Acceleration	meters/s^2	meters/s^2
Angle	degrees or mils	milliradians
Length	meters	meters
Linear dispersion	feet	meters
Speed	meters/s	meters/s
Time	s	s

2.4.2 Coordinates. The model uses two coordinate systems. The first is used for positioning the tanks and is a right-handed coordinate system with the x-axis positive eastward, the y-axis positive northward, and the z-axis positive upward. Angles are measured clockwise from north as is standard with navigation systems and test ranges.

The second coordinate system is centered on the current target with the x-axis positive to the right, the y-axis positive upward, and the z-axis toward the firer. Angles in the target plane (xy-plane) are measured from the y-axis (12:00 position) clockwise.

3. INPUT

The program requires vulnerability data, accuracy data and other miscellaneous data about the systems it is to evaluate, as well as, similar information about threat systems it is expected to fight against. Vulnerability data for fielded systems and for some systems under development are available from the Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD. Accuracy and most of the miscellaneous data are available from the U.S. Army Materiel Systems Analysis Activity (AMSAA). In some cases, data are not available, and good engineering judgement must be used to make an estimate.

Tank Wars requires seven or eight data files to evaluate the combat effectiveness of a single weapon system. These files include a game file; a smoke file, if needed; and three data files to describe each side. The files describing a side include a miscellaneous data file, an accuracy file, and a lethality file. These seven or eight data files are sufficient for one run of the program.

Normally, several runs will be performed to compare the effectiveness of several concepts against a baseline system. After developing the files for the baseline, subsequent runs will require one to six new data files, depending on the manner in which the concept differs from the baseline.

During a single run, the model reads data from seven or eight files and writes to the standard output. One of the input files contains game control information and is assumed to be read from standard input. If smoke is being simulated, a smoke file must be prepared. The other six input files are grouped in pairs, one for Red (threat) data and one for Blue (system being evaluated) data. The first pair contains miscellaneous data about the systems such as vehicle size, visual detection characteristics, firing cycle parameters, and so on. The second pair of files contains accuracy data, and the third pair contains vulnerability data (Pkh tables.)

3.1 The Game Control File. The program reads game control information from standard input. This information determines which scenarios will be played, what combinations of Blue and Red tanks will be used in each scenario, how much input information will be echoed for documentation purposes, how much output information is desired, how many replications are to be performed, and where data on the Blue and Red systems are stored in the computer's mass memory. Table 4 is a sample of such a file.

Line 1 contains values which control the amount of information printed by the program. These are discussed further in this section and summarized in Table 5.

The first value controls the amount of output printed and should be a 0, 1, or 2, where a 0 value produces minimal output (a summary of perhaps 1,000 replications in a few lines), a 1 value produces a one-line summary of each replication, and a 2 value produces a detailed event history (a one-line record of each event in a single replication.)

The second value controls the amount of input data echoed and should be a 0, 1, or 2, where a 0 value causes the program to print only the names of the data files used in the run. A value of 1 causes the program to additionally print the miscellaneous values used, and a value of 2 causes the accuracy data and a sample of the vulnerability data to be printed. The sample of the vulnerability data is for a shot striking the target head on for a fixed dispersion at various ranges. See the output section for an illustration of an input echo.

The third value is not used.

The fourth value controls logic tracing for debug purposes and should be a 0 or a 1. When a 1 value is used, the program prints a line each time a model or driver routine is entered or exited so that the user can trace the logic of the program. It prints a '>name' string when the routine is entered and a '<name' string when the routine is exited. Naturally, a vast amount of output can be generated when this trace feature is on.

Table 4. Sample Game Control File

Data	Comments
2 1 0 0 0	1 Print event history, input echo
0 0 0 0 0	2 Debug prints turned off
500.0	3 Increment in tables (m)
10,1,1,1,1111111	4 Play 10 reps, 1 wave of Reds, cardioid dist, etc.
600.,	5 Max time for an engagement is 600 s
300.,	6 Illumination from sun (ft-candles)
1 smoke	7 Kind of obscuration, name of smoke file
0.,0.,0.,0.	8 Line-of-sight data
1 b.misc	9 Name of Blue miscellaneous parameters file
1 b.acc	10 Name of Blue accuracy data file
1 b.pkh	11 Name of Blue vulnerability data file
1 r.misc	12 Name of Red miscellaneous parameters file
1 r.acc	13 Name of Red accuracy data file
1 r.pkh	14 Name of Red vulnerability data file
1000,3000,500,	15 Vary opening rg from 1–3 km by 500-m steps
1,3,4	16+ Scene, #Blue, #Red (Add as many lines like this as desired.)

The fifth value is also used for debugging and should be a 0, 1, or 2, where a 0 value produces no printing, a 1 value causes each event scheduled, canceled, or executed to be printed, and a 2 value causes the entire list of pending events to be printed when an event is scheduled, canceled, or executed. Again, this generates a vast amount of output.

Line 2 controls further printing of debug information in the model and is not well implemented yet. Use five zeroes for it.

Line 3 contains the range increment for tables of input data. For tanks, it is usually 500.0 (m).

Table 5. Values for Line 1 of the Game Control File

Variable	Value	Resulting Action
1	0	Print only summary of all reps
	1	Print above + summary of each rep
	2	Print above + event history
2	0	Print the names of the data files used
	1	Print above + echo miscellaneous data files and the game control file
	2	Print above + echo the accuracy files and a sample of the vulnerability files for head-on shots and a 2 ft/km dispersion
3		Not currently used
4	0	Omit tracing
	1	Trace entry to and exit from major routines
5	0	Omit printing in the simulation support routines
	1	Print all events as scheduled and canceled
	2	Print above + the list of pending events when scheduled, canceled, or executed

Line 4 contains five integers: the number of replications per case (or wave); the maximum number of waves; a code for the angular distribution to be used for orienting the tanks; a code to select the method of calculating errors against moving targets; and a random number seed. For a production run, the number of replications should be on the order of 1,000; this gives a large enough sample size to draw meaningful conclusions when comparing tank systems. Set the number of waves to 1 if you are not interested in analyzing the effects of ammunition consumption over multiple engagements. The third parameter causes stationary hulls and their turrets to be oriented according to the cardioid distribution if the parameter is set to 1 and oriented according to a more frontally oriented distribution if it is set to 2. The fourth parameter should be set to 1 for the time being. The fifth parameter is the random number seed. It works with the pseudo-random number generator. It is read from input so that a run can be restarted in midstream by suppressing unwanted cases and inserting the starting random number printed for the case of interest.

Line 5 contains the maximum number of seconds allowed for each engagement.

Line 6 contains one value, the illumination of the sun (foot-candles.)

Line 7 contains two values for obscuration. The first value indicates whether terrain or smoke will cause obscuration. Use 1 to indicate terrain and 2 to indicate smoke. The second value is the name of the smoke file. If you are using terrain, just insert a dummy file name.

Line 8 contains four values for terrain. The first two values define the distribution of in-view segment lengths, and the last two define the distribution of out-of-view segment lengths. Tank Wars models in-view and out-of-view terrain segment lengths using the Wiebull distribution. The in-view segment length is

$$l_i = \alpha_1 x^{-\beta_1},$$

and the out-of-view segment length is

$$l_o = \alpha_2 x^{-\beta_2}.$$

(The program draws a random number for x each time it selects a new segment length.) The four values read are α_1, β_1, α_2, β_2. If the obscurant is smoke, use any four real numbers.

Lines 9–14 each contain the types and names of the six data files describing the combatants. Each line contains an integer in 2 columns followed by a legal string of 32 or fewer characters. The first two columns contain the file type (an integer.) Use a '1' left justified in the first two columns for the miscellaneous data files and accuracy data files. (This allows for reading data in different formats later.) Use 1, 2, or 5 for the vulnerability files. A 1 causes reading of 528 lines of KE data; a 2 causes reading of 88 lines of HEAT or missile data; and 5 causes reading of top attack data.

The second value on each line is the file name. Note that the length of file names may be a problem for some compilers. The six file names are read in the following order:

Blue miscellaneous data

Blue accuracy data

Blue vulnerability data

Red miscellaneous data

Red accuracy data

Red vulnerability data

Line 15 controls the opening ranges simulated. If the values are 1000, 3000, 500, then the opening range for the first case will be 1,000 m, for the second 1,500 m, and so on out to the final range at 3,000 m.

Lines 16 and beyond. You may add as many of these as desired. The first value is the scenario desired, where a 1 indicates a meeting engagement, 2 indicates a Red attack, and 3 indicates a Blue attack. The second value is the number of Blue tanks, and the third value is the number of Red tanks.

3.2 <u>The Smoke File</u>. Tank Wars simulates breaks in line of sight caused by intermittent terrain or smoke but not both. If smoke is used, a special file must be created which contains six tables. They consist of the following data:

(1) first out of view for IR band sensors (thermal viewers),

(2) first out of view for visual band sensors (eyes, binoculars, periscopes),

(3) subsequent out of view for IR band sensors,

(4) subsequent out of view for visual band sensors,

(5) in view for IR band sensors,

(6) in view for visual band sensors.

Each table has 21 rows with 5 entries in each row (as shown in Table 6). The program draws a random number and finds the range from the sensor to the target and does a two-way linear interpolation in the table to find the time the target will be in view. For in-view data, the time in view increases as range decreases. The opposite occurs for out-of-view data; time out of view increases as range increases.

Table 6. Time in View for a Visual Band Sensor (s)

Prob	Range (m)				
	0	1,000	2,000	3,000	4,000
0.00	500	210	150	125	100
0.05	500	190	85	80	75
0.10	500	170	63	58	42
0.15	500	150	44	40	26
0.20	500	130	33	28	10
0.25	500	110	26	16	0
0.30	500	90	18	10	0
0.35	500	80	13	4	0
0.40	500	68	9	0	0
0.45	500	55	4	0	0
0.50	500	42	0	0	0
0.55	500	34	0	0	0
0.60	500	25	0	0	0
0.65	500	15	0	0	0
0.70	500	8	0	0	0
0.75	500	4	0	0	0
0.80	500	0	0	0	0
0.85	500	0	0	0	0
0.90	500	0	0	0	0
0.95	500	0	0	0	0
1.00	500	0	0	0	0

The actual data file is free format, with numbers separated by blanks or commas, and looks as follows:

(header line & 21 data lines for 1st IR out of view)
(header line & 21 data lines for 1st visual out of view)
(header line & 21 data lines for subsequent IR out of view)
(header line & 21 data lines for subsequent visual out of view)
(header line & 21 data lines for IR in view)
Time in view for visual sensor (This header line skipped by program)
500. 210. 150. 125. 100.
500. 190. 85. 80. 75.
500. 170. 63. 58. 42.
500. 150. 44. 40. 26.
500. 130. 33. 28. 10.
500. 110. 26. 16. 0.
500. 90. 18. 10. 0.
500. 80. 13. 4. 0.
500. 68. 9. 0. 0.
500. 55. 4. 0. 0.
500. 42. 0. 0. 0.
500. 34. 0. 0. 0.
500. 25. 0. 0. 0.
500. 15. 0. 0. 0.
500. 8. 0. 0. 0.
500. 4. 0. 0. 0.
500. 0. 0. 0. 0.
500. 0. 0. 0. 0.
500. 0. 0. 0. 0.
500. 0. 0. 0. 0.
500. 0. 0. 0. 0.

3.3. The Miscellaneous Data Files. Table 7 contains a sample listing of the file containing miscellaneous parameters for the Blue system. The format for the Red miscellaneous data file is identical.

All of the data are in free format separated by commas. If you want to run the program on a personal computer, be aware that some FORTRAN 77 compilers for PCs only implement the FORTRAN 77 subset. The subset does not read data in free format.

The program echoes the values in the miscellaneous data files when a 1 (or larger number) is placed in the second field of the first line of the game control file.

Table 7. Miscellaneous Data File

Data	Comments
0.75 1.175 1.475 1.475 1.5 1.775 3.375 3.375	1 Turret & Hull dimensions
0 0	2 # of decoys # of flashing decoys
1 8 0.99	3 kind rd, # rds, rd reliability
0.3,.6,.91,1.22,1.55,1.87,2.1,2.4	4 Time of flight
1 3	5 kind sensor, #dets
0.0 0.0 0.6	6 pfalse-HD, pfalse-FE, pinpoint
F	7 Share tgt info
1 1500	8 # priority, recognition rg
0 1 4.5 7.7	9 Halt-to-fire, loader type, tmin, tmedian
3	10 # guidance channels.
7.4,8.8, 10.1,11.4,12.8,14.1,15.4,16.7,	11 Tfirst
0 0.25	12 # rds/burst, time between rds in a burst
4 150.	13 # rds/pod, time to bring up next pod
30 3	14 # rds after M&F kill, time after M&F kill
1 3 60.	15 disengage policy, # rds/tgt, time to look
1. 2. 5. 60.	16 accel, decel, speed, thide

Line 1 contains eight values defining the size of the tank. All measurements are from the center of the turret ring. The tank is treated as a turret box mounted on a hull box, each oriented independently of the other. Figure 1 shows the order in which the dimensions are read from line 1 of the data file, where d_i is the ith value on the line.

Line 2 contains the number of decoys and the number of flashing decoys. These values should be 0 except for the defender.

Line 3 contains information about the round. The first value indicates the type of round, where a 1 indicates a KE round, a 2 indicates a HEAT round, a 4 indicates a missile, and a 5 indicates a direct-fire, top-attack round like STAFF. Table 8 lists the characteristics of each type of round. The second value is the number of rounds on board. The third value is the probability that the round will function. Use 1.00 for the value when simulating KE rounds. For HEAT rounds, 0.98 might be a typical value. For missiles, 0.90 might be a typical value.

Line 4 contains times-of-flight (s) to each of eight ranges. The ranges are multiples of the range increment (from third line of standard input). This value is usually 500 m. If so, the times are flight times to 500, 1,000, ..., 4,000 m.

Line 5 contains two sensor values. The first value is the kind of sensor and is a 1, 2, or 3, depending on whether the sensor is the human eye, a thermal imager that sees through a little smoke, or a thermal imager that can see through a lot of smoke. Thermal imagers are essential to tankers at night and they tend to prefer them during the day too. If you are playing thermal imagers but not smoke, it makes no difference which one you use.

The second value, the number of simultaneous detections, depends on the situation and the system. It determines how many targets are seen at any one time. The target selection routine selects the most dangerous target from those that are seen. If it is night and only the gunner can see using his thermal imager, the number of simultaneous detections should probably be set to 1. If the commander has an independent thermal viewer, or is searching visually, then use a value of 2 or more. If the system has say 5 guidance channels and each target is designated before the system fires, then use a value of 5. In many real world cases, there is no correct value for the number of simultaneous detections; however, the human mind cannot consciously handle more than seven (plus or minus two) items at a time.

Line 6 contains three more sensor values—the probability of detecting a false hull-defilade target, the probability of detecting a false fully-exposed target, and the probability that a single searcher detects a target via its firing signature.

Tankers sometimes see a natural object, identify it as a target, and engage it. This is more common if only the hull of the real target is exposed. No good data exist on how often this occurs. Values of 0.7 and 0.3 have been used for hull-defilade and fully-exposed targets, respectively. Alternatively, you may wish to set these values to 0.

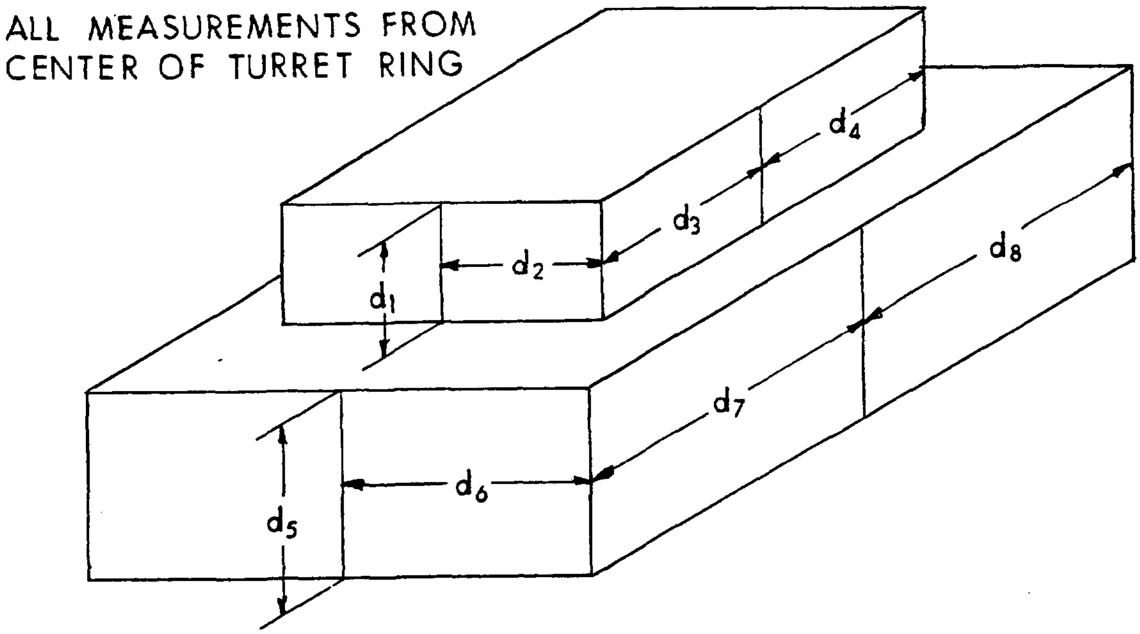

Figure 1. Target Dimensions.

Table 8. Characteristics of Various Rounds

Round	Description	Lines of PKH data	If Firer Is F-Killed
1	KE	528[a]	Rd keeps flying
2	HEAT	88	Rd keeps flying
4	Simultaneous flight msls	88	Abort msls
5	Top attack rounds	? variable	Rd keeps flying

[a] Lethality is a function of range.

When a target fires, its muzzle flash and smoke make it momentarily easier to spot. This is sometimes called pinpoint detection. Values between 0.3 and 0.7 have been used for the probability of pinpoint detection; however, there is no hard data. Pinpoint detection appears to be quite important when detecting hull-defilade targets; values below 0.3 affect the outcome of battles strongly, while a value of 0.3 has about the same effect as a value of 1.0.

Line 7 contains one value for communications between tanks. Normally, it should be set to F (false). This implies that when a tank detects a target, it does not pass the information to other friendly tanks. If you wish to simulate perfect communication between tanks, change this value to T (true). This implies that target information is shared and that friendly tanks will spread their fire as evenly as possible over all known targets.

Line 8 contains two target selection values. The first value is the priority scheme to be used. Combatants will probably use scheme 1 if the probability of a firepower-only kill is low and scheme 2 if the probability is high. Table 2 gives more details about the two priority schemes. The second value is the recognition range used by the priority algorithm. A suggested value is 1500 m or less.

Line 9 contains four values defining the firing cycle. The first value is 1 if the system halts to fire. Any other integer means the system fires on the move. The second value is 1 if there is a manual loader, 2 if the gunner acts in parallel with an automatic loader, and 3 if the gunner acts after the automatic loader. The third value is the mechanical time associated with autoloaders. The fourth value is the median of the variable time between rounds. This is the human reaction time for all the loaders. The logarithm of the variable time is normally distributed.

Line 10 contains one value. It is the number of guidance channels. Use 0 for a fire-and-forget system such as a cannon. Use 1 for a guide-to-impact system such as TOW. For a system that can simultaneously guide n missiles to impact against n different targets, it will be the value of n.

Line 11 contains eight values. The values are the median times to fire the first round against targets at various ranges. The ranges are multiples of the range increment (from third line of standard input. This value is usually 500 m. If so, the times are first fire times to 500, 1000, ..., 4000 m.

Line 12 contains two values for burst fire weapons. If you are not simulating burst firing weapons, use 1,0.0 for the values. For burst fire, the first value is the number of rounds in a burst and the second is the time between rounds in a burst.

Line 13 contains two values for systems firing missiles that are stored in pods. After a system exhausts the missiles in one pod, there is a delay as it brings up the next pod. If the system is in a defensive position, it pops down while "reloading." If you are simulating such a system, set value one to the number of rounds in a pod, and value two to the "reload" time. If not, set value one to the number of rounds on board and value 2 to 0.

Line 14 contains two values defining target disengagement. If a target is M&F-killed, it can neither move nor shoot. It is likely that after a time delay, its foe will recognize it is a less threatening target and switch to other more threatening ones. When n rounds hit the target after an M&F-kill, the target is discarded. When t seconds elapse after an M&F-kill, the target is also discarded. Use n and t as the first and second values. If you don't want disengagement to occur like this, make these large values (999 rounds and 600.0 s, for example). The target is then ignored by all firers. The assumption is that the target has stopped functioning and that those who would engage it recognize that it is nonthreatening after an appropriate delay.

Line 15 contains three more target disengagement values. The first value is the disengagement policy. If it is a 1, 2, or 3, the firer disengages the target immediately if it K-kills the target or after a time lapse if it M&F-kills the target. This time lapse is the shorter of a fixed time (second value on line 14) or the time required to fire a fixed number of rounds (first value on line 14). If it is a 2, the firer disengages the target on hitting it, and if it is a 3, the firer disengages the target after firing a fixed number of rounds at it (second value on this line). Under policies 2 and 3, the target is only partially serviced and the firer will return to K-kill it later if he can.

The second value is the number of rounds to fire at a target before disengaging it. Value 3 is the time (sec) to spend searching for a new target before reengaging a partially serviced target. There are no data for this last value, but 30.0 to 60.0 s seems reasonable.

Line 16 contains four motion values: first, the acceleration of the vehicle (m/s^2); second, the deceleration of the vehicle m/s^2; and third, the maximum speed (m/s) at which the system will move when it is attacking. (In defensive scenarios and meeting engagements, they are stationary.) The fourth value is no longer used. The fifth value is the time (s) required for an F-killed system to reach cover. Since no data are available for this, engineering judgement must be used.

Line 17. The program only reads the first 16 lines, so you can add annotations to the file in subsequent lines.

3.4. The Delivery Accuracy Files. The model reads in delivery accuracies for a stationary firer vs. a stationary target (S-S case), a stationary firer vs. a moving target (S-M case), and a moving firer vs. a stationary target (M-S) case, in that order. The model does not handle a moving firer vs. a moving target. See Appendix A for further discussion of tank accuracy.

Table 9 describes the format of an accuracy file, and Table 10 shows a typical accuracy file. All ranges are in meters and all angular measurements are in mils (1/6,400 of a circle).

3.5. The Vulnerability Data Files. The vulnerability files contain probability of kill information generated by the Survivability/Lethality Analysis Directorate of ARL. These files are called Individual Unit Action (IUA) files. The file for Blue contains Pkh's for a Blue round which strikes a Red target. They assume an aim point near the center of mass of the target (ignoring the target's gun barrel and the portion of track below the hull). Table 11 shows an abbreviated listing of a vulnerability file. Reading from left to right, the columns contain the following:

(1) the target code,
(2) the projectile code,
(3) the range to the target (m),
(4) the exposure code (1 is hull defilade and 2 is fully exposed),
(5) the linear dispersion of the rounds (ft),
(6) the kill criteria (1 is M-kill, 2 is F-kill, 3 is M- or F-kill, 4 is K-kill),
(7–13) the Pkh at 0° to 180° off the nose of the target (in 30° increments),
(14) the Pkh for a weighted average of angles off the nose.

Table 9. Accuracy Data File

Line No.	Format/ Description	Format	Description
			STATIONARY-STATIONARY DATA
1		2i3 a72	# rows, # cols of S-S data Label
2	1a Label	9f8.0	Ranges (m)
3	"	"	Horizontal fixed biases for the first round fired
4	"	"	Vertical fixed biases for the first round fired
5	"	"	Horizontal variable biases for the first round fired
6	"	"	Vertical variable biases for the first round fired
7	"	"	Horizontal random errors for the first round fired
8	"	"	Vertical random errors for the first round fired
			STATIONARY-MOVING DATA
9		2i3 a72	# rows, # cols of S-M data Label
10		a72	Label
11	1a8 Label	8f8.0	Ranges (m)
12	"	"	Horizontal fixed biases at 0° off the nose
13	"	"	Vertical fixed biases at 0° off the nose
14	"	"	Horizontal total error at 0° off the nose
15	"	"	Vertical total error at 0° off the nose
16	"	"	Horizontal fixed biases at 30° off the nose
17	"	"	Vertical fixed biases at 30° off the nose
18	"	"	Horizontal total error at 30° off the nose
19	"	"	Vertical total error at 30° off the nose
20	"	"	Horizontal fixed biases at 60° off the nose
21	"	"	Vertical fixed biases at 60° off the nose
22	"	"	Horizontal total error at 60° off the nose
23	"	"	Vertical total error at 60° off the nose
24	"	"	Horizontal fixed biases at 90° off the nose
25	"	"	Vertical fixed biases at 90° off the nose
26	"	"	Horizontal total error at 90° off the nose
27	"	"	Vertical total error at 90° off the nose
			MOVING-STATIONARY DATA
28		2i3 a72	# cols, dummy data Label
29	1a8 Label	8f8.0	Ranges (m)
30	"	"	Horizontal fixed biases
31	"	"	Vertical fixed biases
32	"	"	Horizontal total random errors
33	"	"	Vertical total random errors

Table 10. Sample Accuracy File

7 9 S-S Errors for Red 9999 (Tbl 9.9–99)

rg(m)	→	250.	500.	1000.	1500.	2000.	2500.	3000.	3500.	4000.
1st	mx	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	my	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	snx	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	sny	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	sx	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	sy	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000

17 8 S-M Errors for a S-123B tank vs. a M-567R tgt. Speed = 10kps

More Info

rg(m)	→	500.	1000.	1500.	2000.	2500.	3000.	3500.	4000.
0deg	mx	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	my	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sx	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
	sy	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
30deg	mx	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	my	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sx	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
	sy	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
60deg	mx	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	my	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sx	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
	sy	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
90deg	mx	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	my	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	sx	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
	sy	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000

5 8 M-S Errors for Blue 9999

rg(m)	→	500.	1000.	1500.	2000.	2500.	3000.	3500.	4000.
FxBh		.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
v		.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Te h		.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000
v		.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000

This is test data

Table 11. Abbreviated Vulnerability File

CODES		Rg	E	D	K	0	30	60	90	120	150	180	Ave
9999	999	0	1	1	1	.784	.907	.919	.855	.911	.920	.918	.868
9999	999	0	1	1	2	.843	.929	.940	.873	.932	.940	.938	.899
9999	999	0	1	1	3	.843	.929	.940	.873	.932	.940	.938	.899
9999	999	0	1	1	4	.542	.629	.633	.598	.627	.638	.634	.601
9999	999	0	1	2	1	.793	.781	.860	.771	.853	.822	.868	.810
9999	999	0	1	2	2	.831	.818	.882	.801	.875	.849	.887	.840
9999	999	0	1	2	3	.831	.818	.882	.801	.875	.849	.887	.840
9999	999	0	1	2	4	.547	.543	.594	.540	.589	.571	.599	.561
.													
.													
.													
9999	999	0	1	11	1	.786	.665	.685	.560	.685	.720	.838	.688
9999	999	0	1	11	2	.816	.743	.773	.684	.773	.780	.856	.764
9999	999	0	1	11	3	.816	.743	.773	.684	.773	.780	.856	.764
9999	999	0	1	11	4	.541	.463	.473	.391	.473	.500	.577	.477
9999	999	0	2	1	1	.862	.917	.957	.958	.954	.965	.912	.923
9999	999	0	2	1	2	.895	.931	.975	.973	.975	.973	.800	.944
9999	999	0	2	1	3	.898	.933	.976	.973	.976	.981	.924	.946
9999	999	0	2	1	4	.645	.702	.704	.747	.701	.730	.587	.695
9999	999	0	2	2	1	.845	.829	.875	.869	.871	.853	.852	.856
9999	999	0	2	2	2	.860	.836	.864	.857	.859	.814	.723	.854
9999	999	0	2	2	3	.866	.850	.891	.889	.891	.869	.862	.875
9999	999	0	2	2	4	.631	.644	.649	.649	.642	.626	.523	.642
.													
.													
.													
9999	999	0	2	11	4	.493	.337	.328	.346	.320	.303	.407	.377
9999	999	500	1	1	1	.784	.907	.919	.855	.911	.920	.918	.868
.													
.													
.													
9999	999	3000	2	11	4	.493	.337	.328	.346	.320	.303	.407	.377

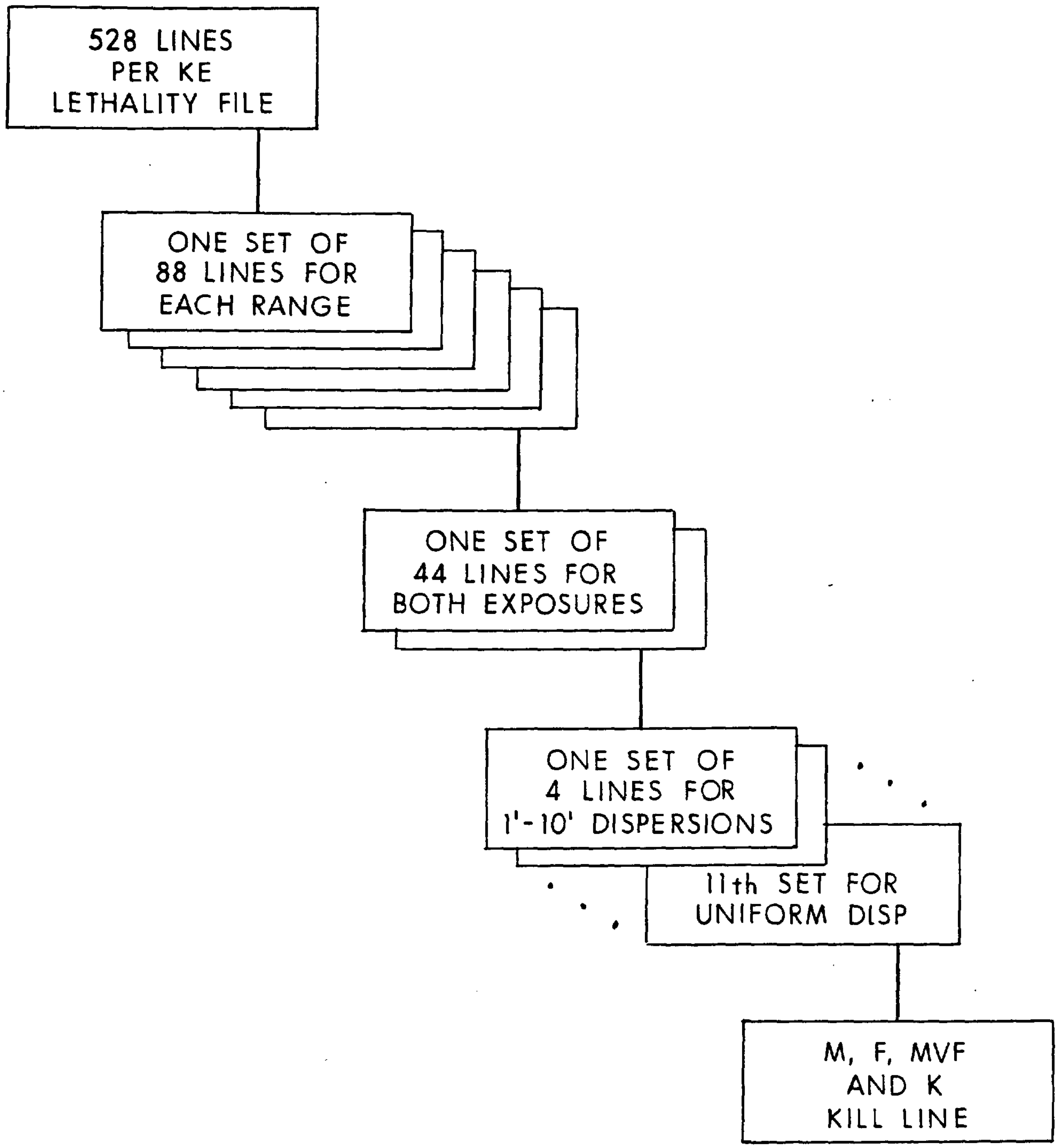

Figure 2. Organization of Vulnerability Data.

Figure 2 shows the organization of the IUA files. For KE rounds, the file contains 6 sets of 88 lines, one for each 500-m range increment, for a total of 528 lines. For HEAT and missiles, there are 88 lines of data that are used for all ranges. This is because the lethality for HEAT and missiles is the same at all ranges (striking velocities). In each group of 88 lines, there are 44 lines for hull defilade followed by 44 lines for fully exposed targets. In each group of 44 lines, there are 11 sets of 4 lines. The 11 sets of lines are for linear dispersions on the target ranging from 1 to 10 ft in 1-ft increments, with the 11th set being for a uniform distribution of shots on the target. (The linear dispersions in the first 10 of these 11 sets of lines are the standard deviations of the circular normal distribution.) Each of the four lines is for a different kill criteria.

4. OUTPUT

Tank Wars II produces varying amounts of output, depending on the print level you specify. This section shows how to change the amount of input echoed to output and how to generate detailed output. If you don't understand the results printed in a brief output, you can rerun the model printing the results of each engagement. Then you can rerun the engagement, printing a detailed event history. Later examples show how to zoom in on these details.

4.1 <u>Level 0: Brief Output</u>. Tank Wars uses the first number on the first line read from standard input to determine how much output it will print. The number can range from 0 to 3, with higher numbers giving more output.

The model produces the smallest amount of output with the print level set to 0. Table 12 illustrates this minimal output. This output contains a three-line header followed by a line indicating whether terrain intervisibility or smoke is being played and a six-line echo of the input file names. Subsequent lines summarize the cases simulated. The information printed is as follows:

LINE INFORMATION

(1) The number of Blue and Red combatants and the scenario.

(2) The starting random number seed and the opening range. This is the range between combatants when the engagement begins.

(3–8) A summary of outcomes and a confidence interval if the sample size is large enough.

(9) The exchange ratio. This is the number of Red systems K-killed per Blue system K-killed.

(10–24) A count of the number of rounds having each type of effect and a count of the number of tanks in each status at the end of the engagements.

The program simulated two cases: seven Red tanks attacking three Blue defenders with opening ranges of 1,000 and 2,000 m. At each range, the model simulated 100 engagements. At 1,000-m opening range, Blue won 54 and Red won 46.

The format of the output is identical for each range. Since the 2,000-m case will be examined in more detail in later examples, the level zero output is discussed below.

At 2,000-m opening range (Blue won 51, Red won 45), there were 3 engagements with survivors on both sides and 1 engagement with no survivors on either side. The sample size is large enough to calculate a 90% binomial confidence interval (it turns out to be 0.424 to 0.596). This means there is a 90% chance that the "true" Blue win probability is between 42.4% and 59.6%. By "true" win probability, I mean the value produced by the program if a huge number of replications were performed. This confidence interval is unacceptably large; 1,000 replications give a much tighter interval and is probably sufficient.

Table 12. Level 0 Output

```
The Sustained Combat Model: Tank Wars II, Version 7.11 Created 5/21/90 by Fred Bunn,
ph (301) 278-6676, DSN 298-6676 Army Research Laboratory, Aberdeen Proving Ground,
MD 21005

Playing terrain intervisibility
 Misc file is: D/r.misc
  Acc file is: D/r.acc
  Pkh file is: D/999vs9999
 Misc file is: D/r.misc
  Acc file is: D/r.acc
  Pkh file is: D/999vs9999
#Blues= 3 #Reds= 7 Red attack
Starting seed= 1111111 Opening range= 1000 m.
```

Table 12. Level 0 Output (continued)

RESULTS	#		90% CONFIDENCE		
Blue won	54	or	0.540	0.454	0.625
Red won	46	or	0.460	0.376	0.547
Draw	0	or	0.000		
All dead	0	or	0.000		
TOTAL REPS	100	or	1.000		

(Red k-killed)/(Blue k-killed) = 3.112

ROUNDS FIRED BY	Blue	Red	SYSTEM STATUS	Blue	Red
Fired	809	709	Alive	103	134
Wasted	0	0	M-killed only	0	0
Aborted	0	0	F-killed only	4	6
False Tgts	0	0	M&F-killed only	23	31
Hidden tgts	6	0	K-killed	170	529
Impacting	803	709	TOTAL	300	700
Misses	4	393	damaged	197	566
Hits	799	316	Alive 1-5 rds	0	0
Duds	6	4	Alive no rds	0	0
No damage	65	41	*future	0	0
M-kill only	2	0	*future	0	0
F-kill only	29	8	*future	0	0
M&F-kill only	163	90	*future	0	0
K-kill	534	173	*future	0	0

Starting seed= 20393039 Opening range= 2000 m.

RESULTS	#		90% CONFIDENCE		
Blue won	51	or	0.510	0.424	0.596
Red won	45	or	0.450	0.366	0.537
Draw	3	or	0.030		
All dead	1	or	0.010		
TOTAL REPS	100	or	1.000		

(Red k-killed)/(Blue k-killed) = 3.127

ROUNDS FIRED BY	Blue	Red	SYSTEM STATUS	Blue	Red
Fired	825	777	Alive	112	149
Wasted	0	0	M-killed only	0	2
Aborted	0	0	F-killed only	5	6
False Tgts	0	0	M&F-killed only	17	24
Hidden tgts	7	1	K-killed	166	519
Impacting	818	776	TOTAL	300	700
Misses	43	486	damaged	188	551
Hits	775	290	Alive 1-5 rds	0	0
Duds	10	3	Alive no rds	0	0
No damage	58	36	*future	0	0
M-kill only	2	0	*future	0	0
F-kill only	25	13	*future	0	0
M&F-kill only	157	69	*future	0	0
K-kill	523	169	*future	0	0

End of run.

Continuing, we see that Red won 45 engagements (or 45%), that the three draws were exactly 3% of the outcomes, and that there was one case of draws where all died. The all-dead case may be more frequent in one-on-one combat where both combatants have a round in the air simultaneously. Later examples will track down this all-dead case. Finally, the total number of replications is 100.

The primary measures of effectiveness are the probability that Blue wins and the exchange ratio. The number of Blue wins divided by the number of replications has a binomial distribution. If the forces are evenly matched and 1000 replications are performed, Blue will win approximately 500 times. Tank Wars can calculate a 90% confidence on the ratio 500/1000, which is approximately ±0.026. Thus, the confidence interval would be 0.474–0.526. The distribution of Blue losses/Red losses is unknown, therefore no confidence interval can be constructed on the exchange ratio.

The next section is entitled "ROUNDS FIRED BY." It tallies the rounds fired by Blue and Red by the effect of each round. In the example, the Red tanks fired 777 rounds. One of these was wasted and 776 impacted. In the wasted category, no rounds were aborted since the rounds were not guided. No rounds were fired at false targets, since false targets were not played. The only wasted round was a round fired at a Blue tank that had just popped down; apparently it had been firepower killed. The other explanation for a round wasted on a hidden target would be that an attacker becomes masked by terrain while the defender's round is in flight.

Turn now to the 776 impacting rounds. Impact implies that the round passes through the plane containing the target and perpendicular to the round velocity. Of these, 486 Red rounds missed the target and 290 hit their target. Of these 290 rounds, 3 were duds, 36 caused no damage, and none caused only mobility damage. Normally hull-defilade defenders suffer no mobility damage or suffer mobility damage in combination with firepower or catastrophic damage since the automotive components are masked by terrain.

Thirteen rounds caused firepower-only damage, 69 caused both firepower and mobility damage, and 169 caused catastrophic damage. A careful examination will show that 251 Red rounds caused kills on 188 Blue tanks.

The final section is entitled "SYSTEM STATUS." It tallies the status of tanks after engagements are won or lost. At engagement end, 149 Red tanks were fully functional, 2 could move but not shoot, 6 could shoot but not move, 24 could neither move nor shoot (but were repairable), and 519 were total losses. In the Blue column, we see that at the end of each engagement every fully functional Blue tank had enough ammunition to participate against the next wave of Red attackers. If a system has no ammo, or fewer than five rounds on board, it doesn't participate in further combat.

4.2 Level 0: Brief Output With Waves of Attackers. We now digress to illustrate the waves feature of Tank Wars. If you are interested in ammunition consumption, use this feature. To do so, set the second value on the fourth line of the standard input file to the maximum number of waves desired. Ten is a reasonable value.

This example is identical to the previous example except that only the first case is simulated—the case with an opening range of 1,000 m and the number of waves are set to 10. With the waves feature activated, Blue survivors regroup in trios to meet groups of seven attackers. The only difference between the Blue systems in the second wave is that they do not have a full load of ammo—only the ammo that was left after engaging the first wave. Blue combatants in the nth wave have whatever ammo remained at the end of the n-1st wave. Table 13 shows the output.

Table 13. Level 0 Output With Waves of Attackers

The Sustained Combat Model: Tank Wars II, Version 7.11 Created 5/21/90 by Fred Bunn, ph (301) 278-6676, DSN 298-6676 Army Research Laboratory, Aberdeen Proving Ground, MD 21005

```
Playing terrain intervisibility
Misc file is:  D/r.misc
 Acc file is:  D/r.acc
 Pkh file is:  D/999vs9999
Misc file is:  D/r.misc
 Acc file is:  D/r.acc
 Pkh file is:  D/999vs9999
#Blues=  3 #Reds=  7  Red attack
Starting seed=  1111111  Opening range=  1000  meters.
Wave 1: Blue, Red won54  46   Draws, all dead=0  0    Low, no ammo=0  0
Wave 2: Blue, Red won16  17   Draws, all dead=1  0    Low, no ammo=0  0
Wave 3: Blue, Red won  6   6   Draws, all dead=1  0    Low, no ammo=0  0
Wave 4: Blue, Red won  1   2   Draws, all dead=0  0    Low, no ammo=0  0
Wave 5: Blue, Red won  0   1   Draws, all dead=0  0    Low, no ammo=0  0
```

Table 13. Level 0 Output With Waves of Attackers (continued)

RESULTS	#		90% CONFIDENCE		
Blue won	77	or	0.510	0.441	0.580
Red won	72	or	0.477	0.408	0.547
Draw	2	or	0.014		
All dead	0	or	0.000		
TOTAL REPS	151	or	1.000		

(Red k-killed)/(Blue k-killed) = 3.105

ROUNDS FIRED BY	Blue	Red	SYSTEM STATUS	Blue	Red
Fired	1201	1033	Alive	1	215
Wasted	0	0	M-killed only	0	0
Aborted	0	0	F-killed only	8	8
False Tgts	0	0	M&F-killed only	35	39
Hidden tgts	8	0	K-killed	256	795
Impacting	1193	1033	TOTAL	300	1057
Misses	7	568	damaged	299	842
Hits	1186	465	Alive 1-5 rds	0	0
Duds	10	7	Alive no rds	0	0
No damage	100	56	*future	0	0
M-kill only	2	0	*future	0	0
F-kill only	43	15	*future	0	0
M&F-kill only	229	127	*future	0	0
K-kill	802	260	*future	0	0

End of run.

The program simulated one case: 7 Red tanks attacking 3 Blue defenders with an opening range of 1,000 m. In wave 1, the model simulated 100 engagements. Blue won 54, Red won 46, and there were no draws. At the end of the 100 engagements in the first "wave," the program counted the remaining Blue tanks that had at least 5 rounds of ammo and could shoot and move. It regrouped these in 34 trios of Blue tanks and pitted each trio against 7 fresh Red tanks. In the second wave, the Blue tanks began the engagements with whatever ammo they had left at their end of the previous engagement. This time, Blue won 16 engagements, Red won 17, and there was one draw with at least 1 survivor on both sides. The draw occurred because a surviving defender had poor detection capability and never detected one of the attackers.

The model played a third, fourth, and fifth wave of attackers after which there were not enough Blue survivors to play a sixth wave. None of the Blue tanks ran low on ammunition.

Since ammo consumption was not a problem, the win and draw probabilities are similar to those in the previous example and so is the exchange ratio. The distribution of results for the rounds is also similar to the distribution seen in the previous example.

The distribution of outcomes for the tanks is where a difference occurs. Since the Blue tanks were thrown into battle repeatedly, only one remained fully functional. Otherwise, the distribution of tank damage is similar to the distribution seen in the previous example wave of Red attackers. If a system has no ammo, or fewer than five rounds on board, it does not participate in further combat.

4.3 Level 1: Summary-of-Engagement Output. If the first number on line 1 of the standard input file is 1, the program prints a one-line summary of each engagement in addition to the brief output discussed in the previous subsection. Use this print level to explore model results. This additional information is useful to demonstrate the model, to develop an understanding of the model, or to track down bugs.

Tank Wars uses the same standard input file that generates Level 0 output (no waves). The only changes are as follows:

(1) The first value on the first line was changed from 0 to 1. This adds the one-line summary of each engagement.
(2) The first value on the fifteenth line was changed from 1000 to 2000. This deletes the first set of results in which the engagements began at opening ranges of 1000 m.
(3) The fifth value on the fourth line was changed from 1111111 to 20393039. This starts the 2000-m engagements with the same random number seed used in the earlier run.

This new information is as follows:

(1) the number of the engagement or replication,
(2) the result (Blue won, Red won, Draw, or All dead),
(3) the number of Blue tanks alive at the end,
(4) the number of Blue tanks only M-killed,
(5) the number of Blue tanks only F-killed,
(6) the number of Blue tanks M and F killed,
(7) the number of Blue tanks K-killed,
(8) a similar summary of the Red tanks,
(9) the starting random number seed.

Table 14 contains an abbreviated sample of level 1 output. The third line of text contains column headings. Column 1 contains the replication number, and column 2 contains the result of the engagement. The four possible results are as follows: Blue won; Red won; a draw with at least one system capable of firing on each side; or a draw with no systems capable of firing on either side.

Columns 3–7 give the status of the Blue systems, and columns 8–12 tell the status of the Red systems. Columns titled AL report the number of Blue and Red systems "alive" at the end of the engagement. These systems are fully functional. Columns titled MO give the number of systems that are "Mobility Only" killed—they can't move. Columns titled FO report the number of systems that are "Firepower Only" killed—they can't shoot. Columns titled MF tally the number of systems that are both "Mobility and Firepower" killed but not "K-killed." And finally, columns titled K give the number of systems that are catastrophically killed (K-killed). The final column lists the random number seed at the beginning of the engagement.

The most interesting engagement was the final replication. There were no survivors on either side. To be more specific, all combatants were at least firepower killed. The next section shows how to print the details of this engagement.

4.4 Level 2: Event History Output. If the first number on the first line of the standard input file is 2, the program prints an event history in addition to the information discussed in the previous two subsections. The event history is a list of times and the events that occurred at those times and may be just a few lines or several hundred lines describing a single engagement, depending on how many events occurred during the engagement. Naturally, if event histories are being produced and a large number of replications are called for, the amount of output will be overwhelming. So use this option carefully.

Table 15 shows a sample event history. It is the final engagement simulated in the previous example. Again, Tank Wars used the same standard input file with the following few changes:

(1) The first value on the first line was changed from 1 to 2. This prints volumes of detail about each engagement.

Table 14. Level 1 Output

.
.
.

#Blues= 3 #Reds= 7 Red attack
Starting seed= 20393039 Opening range= 2000 meters.

Rep	Result	AL	MO	FO	MF	K	AL	MO	FO	MF	K	seed
1	Red won	0	0	0	0	3	3	0	0	0	4	20393039
2	Blue won	3	0	0	0	0	0	0	0	0	7	36283099
3	Red won	0	0	0	1	2	2	0	0	1	4	18469915
4	Blue won	1	0	0	0	2	0	0	0	0	7	29600559
5	Red won	0	0	0	0	3	2	0	0	0	5	1876587
6	Red won	0	0	0	0	3	4	0	0	1	2	15601307
7	Blue won	3	0	0	0	0	0	0	0	0	7	31783123
8	Blue won	3	0	0	0	0	0	0	1	0	6	63752787
9	Blue won	2	0	0	0	1	0	0	0	0	7	37976327
10	Red won	0	0	0	1	2	1	0	0	0	6	47810323
.												
.												
.												
95	Blue won	2	0	0	0	1	0	0	0	0	7	62535239
96	Blue won	2	0	0	1	0	0	0	0	0	7	1782727
97	Red won	0	0	0	0	3	3	0	0	0	4	29280775
98	Red won	0	0	0	0	3	4	0	0	0	3	18170099
99	Red won	0	0	1	1	1	3	0	0	0	4	58903439
100	All dead	0	0	0	2	1	0	0	0	1	6	1034551

RESULTS	#		90% CONFIDENCE		
Blue won	51	or	0.510	0.424	0.596
Red won	45	or	0.450	0.366	0.537
Draw	3	or	0.030		
All dead	1	or	0.010		
TOTAL REPS	100	or	1.000		

(Red k-killed)/(Blue k-killed) = 3.127

ROUNDS FIRED BY	Blue	Red	SYSTEM STATUS	Blue	Red
Fired	825	777	Alive	112	149
Wasted	0	0	M-killed only	0	2
Aborted	0	0	F-killed only	5	6
False Tgts	0	0	M&F-killed only	17	24
Hidden tgts	7	1	K-killed	166	519
Impacting	818	776	TOTAL	300	700
Misses	43	486	damaged	188	551
Hits	775	290	Alive 1-5 rds	0	0
Duds	10	3	Alive no rds	0	0
No damage	58	36	*future	0	0
M-kill only	2	0	*future	0	0
F-kill only	25	13	*future	0	0
M&F-kill only	157	69	*future	0	0
K-kill	523	169	*future	0	0

End of run.

Table 15. Level 2 Output: An Event History

.
.
.

```
#Blues= 3 #Reds= 7 Red attack
Starting seed= 1034551 Opening range= 2000 meters.
  Range to which tank can see
 Tank  HD     FE-S    FE-M    ranu
  1   587.1  1338.0  1713.9  0.1750
  2     9.8   127.8   509.0  0.9845
  3   247.8   782.6  1088.4  0.6069
  Range to which tank can see
 Tank  HD     FE-S    FE-M    ranu
  4   192.4   707.9   984.2  0.6948
  5   443.7  1105.5  1439.3  0.2962
  6   222.2   748.0  1042.5  0.6476
  7   143.7   642.2   857.4  0.7721
  8   110.9   598.0   772.1  0.8241
  9   433.7  1074.9  1421.3  0.3121
 10   363.0   937.9  1294.8  0.4242
 visible for 136.m, then hidden for 600.m.
 visible for 600.m, then hidden for  59.m.
  .
  .
  .
 visible for 376.m, then hidden for 600.m.
   27.14 Red    4 vanishes      (x= 1864.3   y= -300.0)
   27.14 Red    5 vanishes      (x= 1864.3   y= -200.0)
   27.14 Red    6 vanishes      (x= 1864.3   y= -100.0)
   27.14 Red    7 vanishes      (x= 1864.3   y=    0.0)
   27.14 Red    8 vanishes      (x= 1864.3   y=  100.0)
   27.14 Red    9 vanishes      (x= 1864.3   y=  200.0)
   27.14 Red   10 vanishes      (x= 1864.3   y=  300.0)
   147.15 Red   4 appears       (x= 1264.2   y= -300.0)
   147.15 Red   5 appears       (x= 1264.2   y= -200.0)
   147.15 Red   6 appears       (x= 1264.2   y= -100.0)
   147.15 Red   7 appears       (x= 1264.2   y= 0.0)
   147.15 Red   8 appears       (x= 1264.2   y= 100.0)
   147.15 Red   9 appears       (x= 1264.2   y= 200.0)
   147.15 Red  10 appears       (x= 1264.2   y= 300.0)
  150.97 Blue   1 detects Red     6
  150.97 Blue   1 begins selection.
  152.09 Blue   1 detects  Red    7
  152.09 Blue   1 does not select; selecting already.
  152.31 Blue   1 selects Red     6 with priority    19 #tgts= 0
  153.01 Blue   1 detects  Red    5
  153.01 Blue   1 does not select; selecting already.
  159.72 Blue   1 fires at Red    6
  159.72 Red    4 sees    Blue    1 muzzle flash
  159.72 Red    4 begins selection.
  159.72 Red    5 sees    Blue    1 muzzle flash
  159.72 Red    5 begins selection.
```

Table 15. Level 2 Output: An Event History (continued)

159.72 Red	6 sees Blue	1 muzzle flash	
159.72 Red	6 begins selection.		
159.72 Red	8 sees Blue	1 muzzle flash	
159.72 Red	8 begins selection.		
159.72 Red	9 sees Blue	1 muzzle flash	
159.72 Red	9 begins selection.		
159.72 Red	10 sees Blue	1 muzzle flash	
159.72 Red	10 begins selection.		
160.32 Blue	1 K--kills Red	6	
160.32 Blue	1 begins selection.		
160.32 Blue	1 dis-engs Red	6	#tgts= 0
0 Blu dead,	1 Red dead.		
161.24 Red	10 selects Blue	1 with priority	8 #tgts= 0
161.72 Red	4 selects Blue	1 with priority	8 #tgts= 0
162.01 Red	8 selects Blue	1 with priority	8 #tgts= 0
162.11 Red	9 selects Blue	1 with priority	8 #tgts= 0
162.60 Blue	1 selects Red	5 with priority	19 #tgts= 0
162.79 Red	5 selects Blue	1 with priority	8 #tgts= 0
163.08 Blue	1 detects Red	8	
163.08 Blue	1 does not select; selecting already.		
167.32 Red	5 fires at Blue	1	
167.32 Blue	2 sees Red	5 muzzle flash	
167.32 Blue	2 begins selection.		
167.92 Red	5 K--kills Blue	1	
167.92 Red	4 begins selection.		
167.92 Red	4 dis-engs Blue	1	#tgts= 0
167.92 Red	5 begins selection.		
167.92 Red	5 dis-engs Blue	1	#tgts= 0
167.92 Red	8 begins selection.		
167.92 Red	8 dis-engs Blue	1	#tgts= 0
167.92 Red	9 begins selection.		
167.92 Red	9 dis-engs Blue	1	#tgts= 0
167.92 Red	10 begins selection.		
167.92 Red	10 dis-engs Blue	1	#tgts= 0
1 Blu dead,	1 Red dead.		
.			
.			
.			
1 Blu dead,	5 Red dead.		
223.85 Blue	3 selects Red	7 with priority	8 #tgts= 0
227.40 Blue	3 fires at Red	7	
228.00 Blue	3 K--kills Red	7	
228.00 Blue	3 begins selection.		
228.00 Blue	3 dis-engs Red	7	#tgts= 0
1 Blu dead,	6 Red dead.		
229.79 Blue	3 selects Red	10 with priority	8 #tgts= 0
231.89 Blue	2 I-killed.		
231.89 Red	10 begins selection.		
231.89 Red	10 dis-engs Blue	2	#tgts= 0
2 Blu dead,	6 Red dead.		
235.13 Red	10 selects Blue	3 with priority	8 #tgts= 0

Table 15. Level 2 Output: An Event History (continued)

```
238.53 Red    10 fires at Blue      3
238.73 Blue    3 fires at Red       10
239.13 Red    10 MF-kills Blue      3
239.13 Blue    3 would slow up if it weren't already stopped.
239.33 Blue    3 MF-kills Red       10
269.13 Blue    3 I-killed.
3 Blu dead,    6 Red dead.
269.33 Red    10 I-killed.
3 Blu dead,    7 Red dead.
  Rep  Result  AL MO FO MF  K AL MO FO MF  K  seed
   1  All dead   0  0  0  2  1  0  0  0  1  6 1034551
  .
  .
  .
```

(2) The first value on the fourth line was changed from 100 to 1. This tells Tank Wars to simulate just one replication.

(3) The fifth value of the fourth line was changed from 20393009 to 1034551. This sets the random number to the value it had when it simulated the 100th engagement in the previous example.

Some things in the event history need explanation. Time begins at 0 when the systems are deployed and begin searching. The tanks are numbered consecutively with the Blue tanks first; for a case with 3 Blue tanks and 7 Red tanks, the Blue tanks are numbered 1–3 and the Red tanks are numbered 4–10. Whenever a tank halts, the event history gives the xy coordinates.

This engagement is not a typical one. None of the tanks detected enemy tanks in the first 27.14 s of the engagement, at which time the Red tanks went behind terrain. They remained out of view until 147.15 s, at which time they had closed to about 1,264 m. Finally, at 150.97 s, Blue 1 detected Red 6. Major events for Blue 1 are as follows:

At 150.97 s, detects Red 6.
At 152.31 s, selects Red 6.
At 159.72 s, fires at Red 6.
At 160.32 s, K-kills Red 6 (and disengages it).
At 167.92 s, gets K-killed.

Blue 3 and Red 10 are more interesting; they were the last survivors. Near the end of the engagement, they fired near simultaneously and both scored a mobility and firepower kill on the other.

4.5 Input Echo. A single integer controls the amount of input that is echoed to output. The integer is the second number on the first line of the standard input file. If the value is 0, the only information echoed is information about the version of the program and the names of the data files used. If the value is 1, the program also prints, in a well-labeled form, all the miscellaneous tank data used in the current run. And if the value is 2, the program prints the above information plus the accuracy data and a sample of the Pkh data at each range with a dispersion of two feet per kilometer. This gives a fixed dispersion of 0.6 mils. Table 16 shows half of the input echo when the control value is 1. The half shown here describes the Blue combatants; the half not shown describes the Red combatants and has an identical format.

The game file for this illustration is identical to the game file used in the level 0 example except that the number of replications was set to 0, echo was turned on, and the first opening range was set to 2,000 m. Echo was turned on by changing the second value on the first line of the standard input file from 0 to 1. The opening range was changed to minimize the statistical output.

Table 16. Input Echo

The Sustained Combat Model: Tank Wars II, Version 7.11 Created 5/21/90 by Fred Bunn, ph (301) 278-6676, DSN 298-6676, Army Research Laboratory, Aberdeen Proving Ground, MD 21005

ENVIRONMENT:
Illumination is 300.00 ft-candles.
Using frontal distribution.
Rg increment for all tables is 500 m.
Playing terrain intervisibility

====================BLUE SYSTEM CHARACTERISTICS====================

TARGET DIMENSIONS:
Distance (m) from center of turret ring to:

Turret top	0.75	Ground	1.50
Turret Side	1.18	Hull side	1.77
Turret front	1.48	Hull front	3.38
Turret back	1.48	Hull back	3.38

MOTION CHARACTERISTICS:
Acceleration 1.00 m/s**2
Deceleration 2.00 m/s**2
Time to hide 60.00 s
Combat speed 5.00 m/s

---------DETECTION CAPABILITY---------							------FIRING CYCLE-----		
Rg	P-det (ever)			Pdet (1 sec)			Tfirst	Tfixed	Tfly
(m)	HD	FE	FE-M	HD	FE	FE-M	(sec)	(sec)	(sec)
500	0.21	0.94	0.99	0.03	0.15	0.21	7.4	10.0	0.30
1000	0.02	0.35	0.69	0.00	0.05	0.10	8.8	10.0	0.60
1500	0.01	0.09	0.24	0.00	0.01	0.04	10.1	10.0	0.91
2000	0.00	0.03	0.08	0.00	0.00	0.01	11.4	10.0	1.22
2500	0.00	0.01	0.04	0.00	0.00	0.01	12.8	10.0	1.55
3000	0.00	0.00	0.01	0.00	0.00	0.00	14.1	10.0	1.87
3500	0.00	0.00	0.00	0.00	0.00	0.00	15.4	10.0	2.10
4000	0.00	0.00	0.00	0.00	0.00	0.00	16.7	10.0	2.40

ROUND CHARACTERISTICS:
30 KE rounds/tank.
0.99 Reliability of round.

ACQUISITION CHARACTERISTICS:
Visual sensor
3 detections at a time.
0.00 Probability of selecting false HD tgt.
0.00 Probability of selecting false FE tgt.
0.60 Probability of pinpoint detection.
Systems DO NOT communicate tgt locations.

TARGET SELECTION CRITERIA:
Selects old, hit tgts over new tgts.

Table 16. Input Echo (continued)

```
 1500. Recognition rg. (for tgt priorities.)(m)

FIRE CYCLE CHARACTERISTICS:
      System fires on the move
 7.70 Median time between rounds for manual loader (sec).
      0 guidance channels.

TARGET SWITCHING CRITERIA:
Permanently discard:
1. K-killed targets.
2. M&F kill and 30 s elapse or tank fires 3 rds at it.

Misc file is:  D/r.misc
 7  9  S-S Errors for Red 9999 (Tbl 9.9-99)
17  8 S-M Errors for a S-123B tank vs a M-567R tgt. Speed=10kps
 8  5 M-S Errors for Blue 9999
Acc file is:  D/r.acc
Pkh file is:  D/999vs9999

 ===================RED SYSTEM CHARACTERISTICS==================
 .
 .
 .
```

4.6 Logic Tracing. If the fourth number on the first line of the standard input file is nonzero, the program prints logic tracing information. A character string of the form '>subname' and '<subname' is printed whenever a driver or model subroutine is entered or exited, respectively. This tracing information is not printed, however, when the simulation support or utility routines are executed. Take care when turning this feature on because large volumes of output are produced.

If the fifth number on the first line of the standard input file is a one, the program prints a line of information whenever an event is selected for execution, is scheduled, or is canceled. If the fifth number is a two, the program will print this information as well as a complete list of all events that are pending. Take care when turning this feature on because large volumes of output are produced.

5. INSTALLATION TIPS

The program or its forerunner have been installed on the following machines: PDP11/70 under UNIX, VAX under UNIX, VAX under VMS, CYBER under NOS, Honeywell, and IBM. So it should not be difficult to install on any machine capable of running a 75-page FORTRAN program that requires about 35k words for data.

The program and its test cases are generally shipped on tape in two large files, with the first file containing variable length records and the second containing fixed length records. The following specifications are used:

(1) 9-track tape,
(2) 1,600 bpi,
(3) 3,200 char/block,
(4) odd parity,
(5) ASCII character set,
(6) a line feed character at the end of each record.

Both files on the tape contain the following information:

(1) an include file,
(2) the program,
(3) a misc data file,
(4) an accuracy file,
(5) a pkh file,
(6) I/O for case 1: to match input echo,
(7) I/O for case 2: to match a 500-line trace,
(8) I/O for case 3: to match event histories,
(9) I/O for case 4: to match engagement summaries,
(10) I/O for case 5: to match brief output.

Problems may occur in the following areas:

(1) the line feed character at the end of each record,
(2) the program contains tabs for indentation,
(3) the new compiler might not allow include statements,
(4) the new compiler might not allow variable length file names. These are read by subroutine INPUT from the game control file on standard input and passed to the RDMISC, RDEROR, and RDPKH routines.

The following steps must be taken after the tape is copied and is readable:

(1) Split the file into program files, test data files, and output files.
(2) Compile and link the program files.
(3) Run each of the test cases.
(4) Acquire actual data and perform production runs.

The test cases pit identical tanks against each other so in cases where both sides are stationary and have the same number of tanks, the probability of either side winning is 50%, and the results should be close to this if the program executes a large number of replications.

6. CLOSING COMMENTS

The model and its forerunner have served a number of agencies well over a period of years. The reasons for this are multiple. It is written in one of the most widely available scientific languages. It is well structured, so it meets the constantly changing needs of the armor analysis community by being easy to make small changes to the basic code. The stochastic approach makes it reasonably easy to understand what is being simulated, easy to identify unrealistic sequences of events, and to correct problems which are encountered. This understandability also renders the model more credible.

The model is a useful tool for evaluating trade-offs between weapons systems. It has been used for a wide variety of studies. The trade-offs evaluated include a comparison of turret vs. external gun ACVs, where the latter was more difficult to detect and hit but was easier to kill and carried fewer rounds on board. Another study evaluated a system that was more lethal but fired more slowly and carried fewer rounds. A third study evaluated rounds which split into three or more penetrators and consequently had a higher hit probability but lower kill probability given a hit.

APPENDIX:

THE ACCURACY OF TANK CANNON

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U.S. Army Materiel Systems Analysis Activity (AMSAA), Aberdeen Proving Ground, MD, generates massive amounts of accuracy data on armored systems for systems analysis purposes. This data is for stationary firers vs. stationary targets (S-S), for stationary firers vs. moving targets (S-M), and for moving firers vs. stationary targets (M-S); data for moving firers vs. moving targets is not available. This data is presented in tables as angular errors at target ranges from 250 m to 3 km.

Table A-1 below categorizes the types of errors calculated by AMSAA and used by the model. Each error is an angular error expressed in mils and has both horizontal and vertical components. For tank cannon, angular errors are somewhat constant with increasing range, while for missiles, linear errors are roughly constant as range increases. The fixed bias is μ, the variable bias is v, and the round-to-round error is σ. The types of errors depend on the motions of the firer and the target.

Table A-1. Categories of Errors

S-S					S-M	M-S
Single Shot				Burst		
a | 1st	a | h	a | lm	a | sm			
μ v σ	σ	σ	σ	μ σ	μ σ_t	μ σ_t

<u>Stationary-Firer Stationary-Target (S-S) Data</u>. S-S data can be for single-shot firing or for burst firing. Accuracy data for single-shot firing is further divided into the accuracy of the first round (a|1st), a round fired after a hit (a|h), a round fired after a sensed miss (a|sm), and a round fired after a lost miss (a|lm). Each of these cases results in different size of errors.

When a gunner fires the first round at a target, he has a certain accuracy due to the information available. If this round hits the target, this information is then known to be relatively correct, so he will normally use it for the next shot, and his accuracy will be better. If he misses with the first round but senses the impact point (as is often the case with a HEAT round), he will be able to re-aim, but his accuracy will be poorer, so a different set of accuracies must be used.

Finally, if he misses with the previous round and does not observe the impact point (as is usually the case with kinetic energy [KE] rounds and sometimes with high-explosive antitank [HEAT] rounds), his information is then known to be relatively inaccurate.

How well can the gunner sense a miss and adjust his aim? It is generally agreed that the gunner can sense rounds that hit the target and can sense the impact point of HEAT rounds that miss the target. What is not so generally agreed is that the gunner can sense the impact point of a KE projectile which misses its target. The user community says that they can be sensed, but an AMSAA test has demonstrated otherwise. KE rounds may be difficult to sense because the gunner is momentarily disoriented, or no explosion occurs on impact, or because flight times are so short that muzzle smoke and any dust raised have insufficient time to disperse.

It is also rumored that the gunner often re-aims incorrectly. Instead of "moving the burst on target," he moves the crosshairs onto the burst. In other words, he "corrects" in the wrong direction.

In all of these cases, the firing errors can be classified according to how long they persist. Fixed biases are errors that persist over many engagements. They are due to long term conditions such as parallax, a "lot" of ammunition which has abnormal muzzle velocities, an incorrectly calibrated ranging device, and other conditions. Modern fire controls normally reduce this kind of error to a negligible amount.

Variable biases are errors that persist only during the engagement of a single target. They are caused by crosswind, etc.

Random errors are errors that change from round to round and are caused by differences in rounds, microvariations in the environment such as wind gusts, heating of the gun barrel, etc.

<u>Stationary-Firer Moving-Target (S-M) Data</u>. AMSAA prepares tables for S-M cases which contain horizontal and vertical biases and total errors. For modern fire control system, the variable bias is near 0 vertically but is large horizontally. This large horizontal component is induced by the motion of the target. The remaining error is treated as a total error because there are no fixed biases due to the motion of the target. The total error is normally larger than the root

sum square of the random errors and the variable bias found in the S-S cases. Tables of these errors are available for various ranges, target speeds, crossing angles, and evasiveness factors.

Moving-Firer Stationary-Target (M-S) Data. AMSAA also prepares tables for M-S cases, again containing horizontal and vertical biases and total errors. In this case, there are no fixed biases because the firer is moving. Tables of these errors are available for various ranges, firer speeds, and levels of ground roughness.

Moving-Firer Moving-Target Data. The model does not handle a moving firer vs. a moving target. Part of the reason for this is that no data are available in the U.S. I have been told, however, that the West Germans have such data for their models.

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